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| University of edinburgh |
| Design Projects 4 |
| Mars Life Support System Design – Volume 1 |
|  |
| **Group 2** |
| **1/18/2011** |

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| **ABSTRACT** |

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# 1. Introduction

The basic design brief is supplied by the academic supervisors, but the group should expand and comment on it.

**Official Project Brief**

It has been planned that a re-supply mission should return to Mars every 18 months, with the main resources re-supplied being water, oxygen and food. With the current cost of the re-supplement estimated at £1 M/kg, there is a clear need for intensive onsite recycling of the resources, including water, air and waste. Your company has been hired to develop an integrated recycling solution, with an objective to minimize the weight of the re-supplement cargo.  
  
Other technologies that should be explored along with the recycling, include collection and purification of water on Mars and local production of food stock (high protein vegetables etc). The primary source of energy for the Martial station will be provided by a nuclear reactor with up to 50 MWe capacity.

**Expand the brief**

The project brief outlines several design objectives that must be completed;

* Minimise the amount of resources that must be resupplied
* Develop an integrated recycling solution
* Explore alternative sources of resources on Mars

The develop the design methodically, the overall project was separated into three key stages of development. Each stage would establish the design basis for the subsequent stage, enabling the life-support system to be designed systematically and efficiently. This progressive approach enables the optimal system to be designed at each stage despite increasing stage complexity.

* Stage 1 – No resource recycling or utilisation of Mars resources
* Stage 2 – Integrated resource recycling but no utilisation of Mars resources
* Stage 3 – Integrated resource recycling with utilisation of Mars resources

## 1.1 Initial Design Basis – Stage 1

Stage 1 of the design, which utilises no recycling, can be essentially considered the initial basis fo the design. This stage outlines the resupply requirements for the Mars station assuming that there is no life support system in place recycling resources. This allows the maximum cost of resupply to be determined and thus the resupply cost design constraint to be calculated. The resource requirements for the crew of 10 over the period of 18 months were calculated assuming there is no station resource production.

### 1.1.1 Focus Resources

The design of the life-support system requires identification of the resources required for life and a working environment to be maintained. There are many present day examples of isolated systems, such as the International Space Station (ISS) or nuclear submarines, which have life support systems allowing them to remain isolated for long periods before being resupplied. Using the ISS as a basis, several essential resources were identified which must be controlled for life to maintain the system. These are (Hanford Reference);

* Water
* Air
* Waste
* Thermal Energy
* Biomass
* Food

Therefore these are the resources which this design will focus upon. The resupply rate for each resource is determined below.

### 1.1.2 Water Requirement

Water is an essential requirement for life and is used throughout our daily lives for domestic and industrial tasks. It is therefore essential that an accurate water requirement for the Mars station is determined. Due to the many application of water in the station, the requirement was split into two distinct categories;

* Metabolic Requirement
* Domestic Requirement

The metabolic water requirement is that which must be consumed by the crew throughout the resupply period. It was assumed that the Earth recommendation of 2 litres of water per crew member day (cmd) would be consumed (A crew member day is the daily requirement for one crew member. The day time span is an Earth day of 24 hours).

The domestic water requirement is that which is utilised throughout the daily routine of the crew. This includes washing, brushing teeth, laundry and other typical domestic tasks.

The total water requirement for the resupply period is shown in Table 1 below.

|  |  |  |  |
| --- | --- | --- | --- |
| **Total Water Requirement** | | | |
| *Drinking* | *Hygiene\** | *Safety* | ***Total*** |
| [kg] | [kg] | [kg] | **[kg]** |
| 17472 | 92345 | 27454.25 | **137271.25** |

Table - Total Resupply Water Requirement. Hygiene use includes showers, laundry and other domestic consumption. Drinking is based on 2 litres/cmd. (Reference)

A safety factor of 25% was added to the total water requirement to ensure that the crew could survive in the event of an unforeseen circumstances, for example a storage tank leak.

At the proposed cost of £1M/kg the resupply of water would cost £137271M.

### 1.1.3 Air Requirement

Air on Earth has the following molar composition;

* Atmospheric Nitrogen (Assumed N2) 79%
* Oxygen (O2) 21%
* Carbon Dioxide (CO2) trace%

Oxygen is an essential element for life to exist, and is used in respiration for energy production. As this is consumed, resupply would be a requirement. This was calculated using average metabolic rates (IF correct more detail). Oxygen would be resupplied via cryogenic storage to reduce the volume of the resupply, although this would reduce the overall mass requirement.

For this design it was assumed that the station would have the same air composition as on Earth. It was also assumed that the atmospheric nitrogen acts as a buffer gas, neither consumed or produced on the station. This would mean that nitrogen resupply would not be a requirement.

Carbon dioxide is produced in respiration. Although this is not a resupply requirement, it does require removal from the station.

The total air requirement for the mission was calculated as;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Total Air Requirement** | | | | |
| *N2* | *O2* | *CO2* | Safety | ***Total*** |
| [kg] | [kg] | [kg] | [kg] | **[kg]** |
| 0 | 4599 | 0 | 1149.75 | **5748.75** |

Table - Total Resupply Air Requirement. The O2 and CO2 requirements were calculated from metabolic rates. CO2 is negative as this must be removed from the station. The safety factor was applied to O2 only and the CO2 was not taken into account for resupply

With these requirements the total cost of air resupply to the station was calculated as £5749M.

For further design steps the amount of CO2 produced over the resupply period is approximately 5475kg.

In addition to maintain the appropriate composition of air, removal of contaminants and humidity/temperature regulation of the air supply is a requirement that must be taken into account further in the design of the life-support system.

### 1.1.4 Food Requirement

Food is a source of energy for the crew. The stored energy content of the food is transformed into other forms such as work/heat or retained in body mass. Therefore it is very difficult to conserve and will have to resupplied every 18 months.

The mass of food required will ultimately depend upon the type of food that is consumed. However the energy content of the food will be a constant requirement.

To calculate the calorific value of the food consumed, a consumption of 2500kcal/cmd was assumed. This is the average consumption of an active male on Earth.

The calorific requirement of the crew for the mission was calculated as;

|  |  |  |
| --- | --- | --- |
| **Calorific requirement** | | |
| *Standard* | *Safety* | ***Total*** |
| [MJ] | [MJ] | **[MJ]** |
| 57.3 | 14.325 | **71.625** |

Until a specific food-stuff is selected the resupply cost of the food resource cannot be completed.

### 1.1.5 Waste Requirement

Accumulation of waste on the Mars station is a problem that must be addressed. The stations waste can be divided into 3 categories;

* Liquid Waste
* Organic Solid Waste
* Non-Organic Solid Waste

Liquid waste includes urine and grey water. Grey water is that which has been used for domestic applications, which were outlined in section 1.1.1.

Organic solid wastes include faeces and food waste. This waste will also have a low water content. This type of waste is typically freeze dried and stored.

Non-Organic solid wastes are those which cannot be decomposed. These include broken machinery, clothing and discharged equipment such as water filters. This type of waste is difficult to quantify.

Waste is typically dealt with by storage and removal. On the ISS this is achieved by ejecting solid waste on a trajectory with Earth. The solid waste is then incinerated on re-entry to the atmosphere. Fluid waste is either recycled or vented. In submarines the waste is typically stored if solid, or vented if a fluid.

Although the quantity of waste on the station must be regulated, it is a not a resupply requirement. Therefore it is not an essential resource within this design.

For recycling purposes, the liquid waste on the Mars Station is assumed to be all the water that is consumed on the station, thus 137271kg per 18 month resupply period.

### 1.1.6 Thermal Energy Requirement

Thermal energy is an important resource in maintaining an acceptable working environment. The presence of a 50MWe nuclear reactor on the station effectively means that energy supply should not be an issue, and thus any heat requirements could be generated from this reactor. However as engineers it is good practise to minimise the energy requirements for any design, therefore heating must be considered.

For the purposes of this design it has been assumed that the station is perfectly insulated. This closes the system, resulting in heat losses/gains only through the internal system processes. At this stage in the design, no process decisions have been made and thus thermal energy requirements cannot be calculated.

However we are able to discern that with the presence of the nuclear reactor, all thermal energy requirements could be generated using nuclear energy, resulting in no resupply of any fuels for thermal energy generation being required.

### 1.1.7 Biomass Requirement

* Provides salad crop to supplement diet
* Dietary nutrients gained from salad crop are relatively minor
* Main benefit is the psychological advantage that would not be gained from prepared foods
* Potential to use solid waste as fertilizer for food production, but would require prior treatment.

Biomass consists of the organic wastes. It is able to be recycled to create a salad crop. This produces a psychological benefit to the crew as opposed to any physical benefit, although it can reduce the food resupply rate slightly.

The solid waste is treated and used as a fertiliser for salad plants, thus recycling some of the solid waste, which is otherwise difficult to remove.

Although this has several benefits to the station, it is not a resource that must be resupplied and thus it does not apply to this stage of the design. It will potentially be considered in stage 3 of the design, where local resources are utilised to reduce the resupply rate.

## 1.2 Total Resupply Requirements

Combining all of these resources allows the total resupply cost to be calculated.

The total resources, not including food, are;

|  |  |  |  |
| --- | --- | --- | --- |
| Total Oxygen | Total Water | Total Resupply Weight | Total Resupply Cost |
| [kg] | [kg] | [kg] | [£Million] |
| 5748.75 | 137271.25 | 143020 | 143020 |

This is the maximum resupply cost if there is no life-support system recycling resources. Any life-support system that is designed must have a total resupply cost less than this to make it financially feasible.

# STAGE 2

# Process Selection

A reasoned summary of the Group’s process selection and conclusions (This should include a brief description of alternatives, a SWOT, or similar, analysis and a justification of the choice(s) made).

# Process Description

A description of the process(es) designed by the group, accompanied by a process flowsheet to which the description should refer.

* Process Description
* BFD

# Process Chemistry and Data Available

A section on the chemistry, thermochemistry and thermodynamics of the chosen process, including a discussion of the separation processes used and the available data.

# Process Flow Diagram (PFD)

Process flow diagram(s) showing all main plant items (MPIs) and the main process and utility lines connected to them. Each item should have a unique number and a name which describes its function.

# Material and Energy Balances

Material and energy balances in tabular form, referred to stream numbers on the process flow diagram. It is important to include a list of the assumptions made in generating these balances. Operating and design pressures and temperatures should be given with the mass balance

# Equipment List

An equipment list for all MPIs, including key design data for cost estimation (materials of construction, flow rate/capacity/heat load, operating and design temperatures/pressures, basic dimensions/heat transfer surface area, utility (fuel, steam, CW, electrical power) consumption rates, and a brief comment on ‘extras’ (type/number of actual trays, height of packing, weight of catalyst charge, agitator, or type of heat exchanger – whatever may be relevant.).

# Specification and Data Sheets

(j) Data sheets for the MPIs, including the Basis of Design, design data and sketches. Along with the specification sheet, giving the technical data, another sheet is often included giving a description of the duty/service for the item along with the basis of design and any other relevant notes for the equipment design.

# Operating Procedures (including start up and shutdown)

A description of the procedures for normal operation of the plant (whether continuous or batchwise) and for startup & shutdown (continuous processes). This should be confined to general principles, such as the order in which units are to be started, the time taken to reach steady state and whether there are any significant safety considerations or additional equipment required, and not details such as the operation of individual valves.

# Proposed Plant Layout

Plant layout proposals, with justification.

Environmental Impact Assessment  
  
Environmental Impact Assessment ( EIA ) of the Plant. Rates, including compositions and phase (gaseous, liquid or solid) of by-product and waste streams, and the group’s proposals for treatment, cleanup, substitution or elimination.

# Process Safety

Hazards of the process (flammable/toxic properties of the chemicals used/made, their inventory and operating conditions in the process). Recommended safety protection systems (e.g. blowdown/quench drums, flarestacks) & emergency shutdown procedure(s).

# Economic Assessment

Economic assessment of the project This will include a summary list of raw materials/feedstocks, catalyst and utilities consumptions leading to the variable costs of production, capital and installed costs of equipment and income from sale of the product(s). Net Present Value, Discounted Cash Flow Rate of Return or other economic indicators should be used to judge the attractiveness of the project.